AN EVALUATION OF FRUIT DETACHMENT CHARACTERS IN PEPPERS (*Capsicum annuum* L.)

By

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The fruits produced by the pepper lines PI 224405 and 68-14 separated easily from the plant at the node and between the calyx and fruit. They were crossed with "bell" cultivars, 'Early Calwonder', and the line, 23-1-7, so that these detachment characters could be evaluated in the F_2 and backcross progenies.

The mean pull forces of the fruits at the calyx detachment site in the backcross and F_2 progenies of PI 224405 and 'Early Calwonder' crosses were significantly correlated to the stem scar diameter.

Statistical differences between the mean pull forces of fruits of the parent lines, F_2, and backcross progenies indicated that the detachment characters were under genetic control. In the populations tested, the mean pull force at the node was smaller than the mean pull force at the calyx.

Comparisons of fruits with a stem scar, as found in calyx-detached fruit, and fruits with a jagged pedicel found in hand harvested fruit, indicated that there were no significant differences between the two types as to weight loss during storage, or to the customer preference when the peppers were sold.

The fruits of eight cultivars were tested to ascertain whether fruit with an exposed stem scar would be more susceptible to bacterial soft rot caused by Erwinia carotovora than fruit having a jagged pedicel. There was no difference in the tolerance to soft rot between the two treatments in fruits of 'Allbig', 'Avelar', 'Keystone Resistant Giant', 'Yolo Wonder' and 'Jalapeno' ten days after inoculation. Calyx-detached fruits of 'Early Calwonder', 'Hot Portugal', and 'Large Red Cherry' were more susceptible than the jagged-pedicel fruits.

Significant differences in the tolerances to soft rot were found among cultivars. The fruits of 'Jalapeno' demonstrated the highest tolerance in both fruit types, while the degree of tolerance varied in the remaining cultivars as to fruit type and to time after inoculation.

INTRODUCTION

Florida growers harvested 12,800 acres of bell peppers (*Capsicum annuum* L.) in 1972, which had a total worth of $22,772,000 (19). The harvesting of this crop is accomplished primarily by hand by grasping the fruit and snapping the pedicel. Little is known of the factors that effect the separation of the fruit from the plant. The present method of hand harvesting usually results in a jagged edge on the pedicel which can scar or puncture other fruit in handling and marketing. The pedicel is also a site for soft rot development.

The rapid depletion of the labor force has seriously hurt Florida production, and this important crop will continue to be difficult to harvest unless another method of harvesting and handling is found for the fresh market trade.

The incorporation into bell pepper cultivars of a natural detachment character that requires less force of fruit separation would simplify harvesting tremendously. This would be true of fruit that are hand picked and could influence the development and subsequent use of mechanical harvesters.

The purpose of this study was to observe and evaluate fruit detachment characters that would facilitate hand and/or mechanical harvesting.

In evaluating these characters, more than the ease of detachment was considered. The marketability, storage quality, and the alteration of susceptibility to soft rot were of prime importance. The incorporation of a detachment character into a commercial line would not be advisable if that character lowered the marketability or storage quality of the fruit or if it predisposed the fruit to invasion by soft rot bacteria.

For these reasons, several experiments were conducted to test the consequence of a change in the detachment point on a bell pepper.

LITERATURE REVIEW

The peppers are considered native to tropical America. In 1886, DeCandolle concluded that no Capsicum is indigenous to the old world due to the lack of any reference to this genus in ancient languages (4).

The center of origin of the common cultivated pepper (*Capsicum annuum* L.) is Mexico, with a secondary center in Guatemala (16). The Olmecs raised "chilis" before the time of the Toltecs and peppers are mentioned frequently as an herb in the edible dishes of the Aztecs (6, 25). Peppers have also been recovered from prehistoric burial sites in Peru.

Peppers were introduced to the old world by Columbus on his first voyage (6, 16, 25). The cultivation of pepper then spread from the Mediterranean region to England by 1585 and to Central Europe by the close of the 16th century. The Portuguese took peppers to India from Brazil prior to 1585 and cultivation was reported in China during the late 1700's (25).

The genus *Capsicum* is a member of the *Solanaceae* or nightshade family. Linnaeus in his *Hortus Clifforensis* (1737) described two species, *C. annuum* and *C. frutescens*.

A wide range of forms are found in the genus and each variation was considered a species or botanical variety in early taxonomic treatment. Over 100 supposedly good species have been described (6, 16).

The cultivated Capsicums have now been consolidated into five species: C. annuum L., C. frutescens L., C. pendulum Willd., C. pubescens R. & P., and C. chinense Jacq. (14, 24).

By current rules of botanical nomenclature, the terminology C. annuum L. is correct for all the common peppers cultivated in the United States, with the exception of the 'tobasco' which is C. frutescens.

In 1951, Smith reported a "deciduous" character in ripe pepper fruit which was under single gene control (23). The deciduous ripe fruit detached very easily between the calyx and pod. The character also segregated independently to the spicy or pungency character (8). The deciduous character is found in many wild species (23). The term deciduous was redesignated soft flesh (16), in lieu of the fact that detachment was principally a result of a break down in the wall and placental tissue.

An abscission layer normally develops in tomato fruit pedicels at a joint located mid-way between the fruit and the stem. When these tomatoes are mechanically harvested, the pedicels attached to the fruit often damage other fruit. This problem has been reduced considerably by the development of jointless tomato lines. The separation, in this case, is between the fruit and pedicel. Harvesting results in a stemless fruit. An intensive effort is under way in evaluating tomato pedicel detachment for the mechanization of fresh market tomato harvesting (7, 26).

Snap bean cultivars vary widely in the force necessary to detach the pod from the plant and in the location of the detachment points (2, 22). The snap bean is similar to the pepper in that there is no joint or abscission layer between the fruit and the stem on the pedicel.

Hield et al. (9) found that detachment force was reduced when citrus fruit were pulled at a 45 degree angle from the fruit-pedicel axis. They also found linear correlations between detachment force and both fruit size and stem size.

The pungency or spicy flavor of Capsicum fruits is due to the alkaloid capsaicin. Ohta found that capsaicin was produced in secretory cells located along the placenta (16). When peppers are classified on the pungent and non-pungent criteria, segregation of pungency or capsaicin production is reported to result from the presence of a single dominant gene, C (8). The variation of pungency in plants of the same genotype has been attributed mainly to the size of fruits, along with soil and climatic conditions (6).

Crosses of elongate by oblate fruit gave F_2 distributions that indicate a major gene for fruit shape (5). The gene O for oblate fruit shape as opposed to elongate is inherited as completely dominant in a cross where the length/width shape index is 2.0 (20). In crosses where the shape index is 4.0, segregation is less distinct and intermediate classes indicate either an incomplete dominance for the oblate gene for the influence of additional genes operating in the control of fruit length (16).

Fruit width is postulated to depend primarily on fruit shape and weight factors. If width genes are present, they would cause only minor deviations in the shape expression (16).

Immature fruit color varies from dark purple through shades of green and yellow to ivory or sulfur white. Gene A controls purple fruit color and is completely dominant to non-purple fruit color, although various shades of purple are evident (20). Green and yellow immature fruit colors have been reported to segregate into 3:1 F_2 ratios (16). A series of dominant factors appear responsible for chlorophyll intensity in unripe green types. Peterson (20) suggested the $\underline{G}_1\underline{G}_1$, $\underline{G}_2\underline{G}_2$ genotype for cedar green while lettuce green would be $\underline{G}_1\underline{G}_1$. $\underline{g}_2\underline{g}_2$ or $\underline{g}_1\underline{g}_1$, $\underline{G}_2\underline{G}_2$. Sulfur white would be the absence of green color or $\underline{g}_1\underline{g}_1$, $\underline{g}_2\underline{g}_2$. It has later been suggested that this is controlled by factor pairs, designated $\underline{sw}^{+}_{1}$, $\underline{sw}^{+}_{2}$, $\underline{sw}^{+}_{3}$, $\underline{sw}^{+}_{4}$, ... $\underline{sw}^{+}_{n}$ (15, 16). The presence of two factor pairs produces lettuce green while four factor pairs produce cedar green. Sulfur white pods result from the absence of all chlorophyll factor pairs.

The differences in fruit orientation in the Capsicums have been noted. The pedicel of pendant fruit is recurved at maturity so that the stigmatic end of the fruit points downward. The pedicel of erect fruit is vertical and erect, the tip of the fruit pointing upward. This difference in fruit position has been used as a diagnostic character in the classification of species (6).

Kaiser presented evidence that the pendant fruit is dominant over erect fruit (13, 14). The F_2 segregates indicated a single gene difference which was an expression of a genetically determined geotropic growth response. Since this character is a result of a growth response, young fruit on a plant with a pendant phenotype may still be upright, i.e., on a single plant both pendant and erect fruit may be found. Determination must be made over a period of time during the growing season. The gene $\underline{up}$ has been designated for upright pedicel which is recessive to $\underline{up}^{+}$ for pendant or drooping pedicel (14, 15, 16).

Pedicel length seems to be inherited as a quantitative character. Short pedicel appeared to be dominant over long pedicel (15). Short pedicel also seems to be associated with purple plant color (5).

Bacterial soft rot caused by Erwinia carotovora (L. R. Jones) Holland is one of the most destructive post harvest decays of bell pepper (10, 11). L. R. Jones reported in 1901 that the soft rot bacteria did not penetrate the intact surface of vegetables (12). The bacteria gain entry through broken stems, wounds, and surface cracks. Johnson (11) stated that in peppers, broken stems resulting from harvesting, provide an ideal entry point for infection following contact either with contaminated soil or picking and packing equipment. The stem and calyx tissue in this case are infected first, followed closely by infection of the fruit. Johnson also compared the relative susceptibility of three types of stem breaks, namely, clipped, jagged, and natural type which results from formation of a normal abscission layer. He found that the natural (abscission) type showed an inherent resistance to infection. In the field and packing shed, the clipped type of stem break was more tolerant than the jagged type, but much less tolerant than the natural type.

Using decay control tests with inoculated peppers, Johnson suggested that susceptibility to soft rot infection may vary between seasons and between specific fields of peppers in the same season.

Magruder in 1937 reported that rutabaga and turnip varieties differed in susceptibility to soft rot epiphytotic in the field (18). No attempt was made, however, to provide uniform predisposing factors such as, insect damage, wounds, etc.

Bartz and Crill (1) proved that three tomato cultivars differed in their tolerance to soft rot caused by Erwinia aroideae, a non-gas forming varient of E. carotovora. They found that exposure to chilling at 7.2°C (45°F) for 5 days or increase in inoculum concentration from

10^5 bacteria/ml to 10^7 bacteria/ml gave a marked increase in the amount of fruit decay in each cultivar. When reported on a unit time basis, the cultivar differences in tolerance were not altered.

A temperature range of 7.2°-10°C (45°-50°F) at 85 to 90% relative humidity is recommended for storing bell peppers (17, 21). They are subject to chilling injury below 7.2°C. Peppers held below this temperature long enough to cause serious chilling injury also develop numerous lesions of alternaria rot, and are predisposed to botrytis decay and soft rot infection. Storage temperatures above 10°C encourage ripening and development of bacterial soft rot. Under the most favorable conditions, bell peppers should not be stored longer than 2 to 3 weeks (17, 21).

MATERIALS AND METHODS

In the spring of 1972, 73 pepper lines from 8 seed companies, encompassing 68 separate cultivars, were planted along with 31 breeding lines and wild types. They were observed and evaluated for fruit detachment characters that would facilitate hand and/or mechanical harvesting in the mature green state.

The peppers used in most tests were from plants started in the greenhouse and transplanted on a four foot black plastic mulch bed on Kanapaha fine sand at the University of Florida horticultural unit at Gainesville, Florida.

Initial fertilization was 1,800 lbs/acre 6-8-8 with fritted, minor elements. Additional fertilization was incorporated when deemed advisable due to plant response and climatic conditions.

Fruit Detachment Tests

Several lines with small, pungent fruit showed promising fruit detachment characters. These were crossed with commercial bell types and/or advanced breeding lines in which these characters were not found. The crosses were made both in the field and in the greenhouse.

F_1 progeny and parent lines were grown in the fall, evaluated, selfed and backcrossed to parental lines. F_2 plants along with backcross progeny and parental lines were grown in the spring of 1973.

The fruits from the plants grown in the spring of 1973 were evaluated for pull force at the calyx and the node detachment sites.

A strain gauge, the Ametek Model LKG-5 with a metric scale was used for the direct measure of the pull force. The pull force per plant was obtained by averaging the measurements of approximately 10 fruits per plant.

PI 224405 and 68-14 were crossed with 'Early Calwonder' and 23-1-7. PI 224405 is designated P1 for parent 1, 'Early Calwonder' as P2 for parent 2, 68-14 as P3 for parent 3, and 23-1-7 as P4 for parent 4.

The mean of the pull forces for the second filial generation (F_2) of of the cross (P1 x P2) was compared with the pull force means of the populations of P1, and F_2 of the reciprocal cross (P2 x P1), and the F_2 of the cross (P3 x P2). The mean pull force (MPF) of (P2 x P1)F_2 was compared with the MPF's of (P1 x P2)F_2, the backcross of the F_1, (P2 x P1) with P2 and P1 and the F_2 of the cross (P2 x P3).

Besides those mentioned above, the MPF of the F_2 of (P3 x P2) was compared with the MPF of the F_2 of (P2 x P3), (P3 x P2)F_2 and the MPF of the parent, P3. The MPF of (P3 x P4)F_2, besides being compared with the MPF of (P3 x P2)F_2 was compared with the MPF of P3 and the MPF of (P3 x P4) backcrossed to P4.

Selection of a plant that demonstrated fruit with a low pull force was made in the 68-14 (P3) population. Seeds from a self pollinated fruit were planted and selection for low pull force was again made. A population of plants from seeds of the second selection were grown in the spring along with the parent P3 population. They were designated 68-14-1-1 and were not used in the P3 pull force averages.

The fruit width at the stem end and the stem scar diameter were recorded and tested for significant correlation with the mean pull forces of the fruit at the two detachment sites in all populations. The length, shape, and color of fruits were also noted. Analysis of population means, adjusted and unadjusted, were made by the analysis of variance method.

Soft Rot Tests

Mature green fruit from the cultivars, 'Allbig', 'Avelar', 'Early Calwonder', 'Hot Portugal', 'Jalapeno', 'Keystone Resistant Giant', 'Large Red Cherry', and 'Yolo Wonder', were hand harvested from adjacent rows in the spring of 1973. The fruits were brought directly to the laboratory where the pedicel and calyx were mechanically removed from the fruit of one-half of each cultivar. These fruits displayed an open stem scar and constituted the calyx-detached treatment. The remaining fruits with the calyces and jagged pedicels attached were used as the control treatment. The fruits from each cultivar were divided into 10 fruit samples with three replicates per treatment.

A 5 x 10^6 cells/ml suspension in buffered saline was prepared from a 24 hour Erwinia carotovora nutrient broth culture as described by Bartz and Crill (1). The inoculum was sprayed on the stem end of each pepper with an atomizer. Each pepper received approximately 1.5 ml of the suspension. The inoculated peppers were stored at 21.1°C (70°F) and ca. 90% relative humidity. Fruit with visible soft rot symptoms were removed and recorded at 3, 5, 7, and 10 days after inoculation.

Arc-sine transformation of zero (no-rot) to 100 (all-rot) percentage values was performed before statistical tests were applied to the data. Significance between treatments of the same cultivar was tested by the analysis of variance method. Mean differences in tolerance to soft rot among cultivars were tested by Duncan's new multiple range test.

Customer Preference

Bell peppers were sold during three weeks in the fall of 1972 and five weeks in the spring of 1973 to study the relative preference of customers to bell peppers without pedicels and calyces as opposed to peppers with pedicels and calyces intact.

The fruit were sold from an open display at Brown's Farm Market, Orange Heights, Florida. Both types of peppers, calyx removed and calyx attached, were mixed in the display. All peppers were sold at the same price. The customers picked the pepper or peppers that they desired.

'Yolo Wonder' fruits were picked Thursday evening or Friday morning, washed, graded and the pedicels and calyces removed from one half of the total fruit. The remaining fruits were of the jagged-pedicel type, which is the normal condition in which most bell peppers are sold. The peppers were sold from Friday noon through Saturday of each week.

The number of peppers sold per day and per week was recorded. Comparison of the preference between the two pepper types was accomplished by using Student's paired t test.

Storage Tests

Fruits of 'Early Calwonder' were stored at 21.1°C (70°F) and ca.

80% relative humidity for two weeks to test the holding quality of peppers with pedicels and calyces removed.

The peppers were hand harvested and brought to the laboratory where they were washed and graded. Twenty peppers were used in each sample. Each pepper was initially weighed and the weights were individually weighed and recorded and constituted the calyx-detached treatment. The remaining fruit of the jagged-pedicel attached type constituted the control treatment. The two treatments were replicated five times.

Each replicate was stored for 14 days. At the end of this period, the peppers of each treatment were again weighed. The pedicels and calyces were also removed from peppers of the control treatment and the fruits were again weighed.

The storage quality of each treatment was determined by the percent weight loss. Weight loss per pepper was figured two ways. The weight of the calyx-detached pepper after 14 days was subtracted from its initial calyx-detached weight. This average was compared with average weight loss of the peppers of the control treatments. The weight of the calyx-detached peppers after 14 days was also subtracted from the initial weight before the pedicels and calyces were removed. This was compared with the peppers in the control treatments initial weight minus their weight after 14 days when the pedicels and calyces had been removed.

Differences in percent weight loss were tested by the analysis of variance method.

RESULTS

Fruit Detachment

In the first plantings in the spring of 1972, two types of fruit detachments were observed. The first was the natural (abscission) type of detachment where the pedicel separated from the stem at the node. The harvested pepper contains both the fruit and a blunt end pedicel.

The second type of detachment was where a separation between the fruit and pedicel occurred at the calyx. The harvested pepper would then consist of only the pod, while the pedicel and calyx remain attached to the plant. This is not to be confused with the soft wall character controlled by the gene S in which the ripe fruit walls and placenta tissue break down (8, 15, 23).

Most bell-type cultivars exhibit a high degree of attachment at the node and at the calyx, while many wild types exhibit degrees of easy detachment at one or both locations. The pull force at the calyx is unmeasurable in most bell-type cultivars. The force of attachment is so strong that the fruit will tear, the pedicel will break, or in many cases, the whole plant will pull from the ground before any separation occurs. However, when looking through large populations, one or more plants may be found that demonstrate the calyx separation character, but the pull force is usually very high (8-10 kg).

Easy separation at the node is a character that can be found in more cultivars than that of calyx separation. 'Jalapeno' fruits, however, separate readily at both locations, while fruits of Hungarian and Rumanian types separate readily only at the node.

In the varieties tested, many wild types exhibited both separation types. Of these, the lines 68-14 and PI 224405 were crossed with 'Early Calwonder', a bell type cultivar, and with 23-1-7, a breeding line that exhibit high attachment at both locations.

The data in Table 1 illustrate the mean pull force at the node and calyx, the average stem scar diameter and average fruit width for P1, P3 and all the F_2 and backcross progenies studied.

In the F_2 and backcrosses of the PI 224405 and 'Early Calwonder' (P1 and P2) crosses, the average pull force at the calyx was significantly correlated to the stem scar diameter. In comparing the means of the populations, the pull force was adjusted for the stem scar diameter. A significant correlation was found between the pull force at the node and the fruit width. In the comparisons at the node, the pull force was adjusted for the fruit width.

The mean pull force as measured at the node was lower than the pull force at the calyx in P1, P3 and all crosses. The pull forces on P2 and P4 were non-measurable. The fruit would tear, the pedicel would break, or the whole plant would be pulled from the ground before separation occurred. Therefore, these populations could not be included in the comparisons.

The data in Table 2 compare the mean pull forces for separation between fruit and calyx.

The mean pull force (MPF) for fruit-calyx separation of P1 is significantly lower than the MPF of P3.

Table 1. Comparative fruit and detachment measurements of the pepper populations studied.

Population	Mean Pull Force (kg)		Average Diameter (mm)	
	Calyx[z]	Node[y]	SSD[x]	Fruit
(P1 x P2)F_2	3.11*	1.13**	6.18	24.78
(P2 x P1)F_2	3.04*	1.23	6.76	24.46
(P2 x P1) x P1	1.63*	0.93	4.78	15.75
(P2 x P1) x P2	3.38*	1.13**	7.78	28.89
(P3 x P2)F_2	3.61	1.93	11.08	40.00
(P2 x P3)F_2	4.93*	2.03	13.25	50.50
(P3 x P4)F_2	2.29	0.96	7.96	26.04
(P3 x P4) x P4	2.92	0.90	10.93	39.27
(P3)	2.57*	0.71	6.65	18.68
(P1)	0.68	0.46**	2.18	7.60

* Significant correlation with stem scar diameter.

** Significant correlation with fruit width.

[z] Separation between calyx and fruit.

[y] Separation between pedicel and stem at node.

[x] Stem scar diameter.

Table 2. Comparisons of population mean pull forces at the fruit-calyx detachment site.

Population	Mean Pull Forces (kg)	
	Unadjusted	Adjusted for SSD[z]
(P1 x P2)F$_2$	3.11	2.90
(P1)	0.68**	0.76**
(P1 x P2)F$_2$	3.11	3.18
(P2 x P1)F$_2$	3.04	3.01
(P2 x P1)F$_2$		
(P2 x P1) x P1	1.63**	2.21**
(P2 x P1)F$_2$	3.04	3.08
(P2 x P1) x P2	3.38	3.11
(P1 x P2)F$_2$	3.11	3.41
(P3 x P2)F$_2$	3.61	2.88
(P2 x P1)F$_2$	3.04	3.24
(P2 x P3)F$_2$	4.93**	2.15**
(P3 x P2)F$_2$	3.61	3.81
(P2 x P3)F$_2$	4.93	4.29
(P3 x P2)F$_2$	3.61	2.99
(P3 x P4)F$_2$	2.29**	2.01*
(P3 x P4)F$_2$	2.29	1.99
(P3 x P4) x P4	2.92**	2.52*
(P3 x P4)F$_2$	2.29	2.06
(P3)	2.97	2.91
(P3 x P2)F$_2$	3.61	2.83
(P3)	2.97**	2.91*
(P3)	2.97	1.63
(P1)	0.68**	0.74**

* Values significant at the 95 percent probability level.

** Values significant at the 99 percent probability level.

[z] Stem scar diameter.

The mean pull force of the F_2 cross, P1 x P2, is significantly higher than the MPF of the easy pull parent, P1. The MPF of the reciprocal crosses P1 x P2 and P2 x P1 in the F_2 generation are not significantly different. Also, in the F_2 generation, P3 x P2 is not significantly different from its reciprocal cross.

The MPF of the (P2 x P1)F_2 is significantly higher than P2 x P1 backcrossed to the easy-pull parent, P1. The F_2 of this cross is lower, but not significantly, however, than the MPF of the backcross to the hard pull parent, P2. The MPF of the (P3 x P4)F_2 is significantly lower than the MPF of P3 x P4 backcrossed to the hard pull parent, P4.

When the easy-pull parents, P1 and P3, are used as the female parent and crossed with P2 as the pollen parent, the MPF of the F_2 populations, (P1 x P2)F_2 and (P3 x P2)F_2, are not significantly different. If P1 and P3 are used as the pollen parents in a cross with P2, and F_2 generations are significantly different for the MPF at the fruit-calyx detachment point.

The MPF of the F_2 of (P3 x P4) is not significantly different from the MPF of P3. The MPF of the (P3 x P2)F_2 is, however, significantly larger than the MPF of P3. Also, the MPF of (P3 x P4)F_2 is significantly lower than the MPF of (P3 x P2)F_2.

The mean pull force for the population 68-14-1-1, i.e., the selection for two generations from 68-14 (P3), was 1.95 kg. This was much lower than the 2.97 kg for the mean pull force of P3. No test of significance was made on the two populations, however.

Comparisons between mean pull forces as measured at the node were also made for the populations (Table 3).

Table 3. Comparisons of population mean pull forces at the node detachment site.

Population	Mean Pull Forces (kg)	
	Unadjusted	Adjusted for FW^z
(P1)	0.46	0.0
(P1 x P2)F_2	1.13**	1.01**
(P1 x P2)F_2	1.13	1.12
(P2 x P1)F_2	1.23	1.22
(P2 x P1)F_2	1.23	1.22
(P2 x P1) x P1	0.96	1.05
(P2 x P1)F_2	1.23	1.22
(P2 x P1) x P2	1.13	0.92
(P1 x P2)F_2	1.13	1.27
(P3 x P2)F_2	1.93**	1.86**
(P2 x P1)F_2	1.23	1.25
(P2 x P3)F_2	2.03**	2.26**
(P3 x P2)F_2	1.93	1.96
(P2 x P3)F_2	2.03	2.10
(P3 x P2)F_2	1.93	1.85
(P3 x P4)F_2	0.96**	1.09**
(P3 x P4)F_2	0.96	1.09
(P3 x P4) x P4	0.90	0.95
(P3 x P4)F_2	0.96	1.09
(P3)	0.71**	0.72
(P3 x P2)F_2	1.93	1.82
(P3)	0.71**	0.73**
(P3)	0.71	0.69
(P1)	0.46*	0.00**

*Values significant at the 95 percent probability level.

**Values significant at the 99 percent probability level.

^{z}Fruit width.

The mean pull force (MPF) at the node of the easy pull parents, P1 and P3, were significantly lower than the F_2 crosses with the hard pull parents in the unadjusted comparisons. That is, the MPF of $(P1 \times P2)F_2$ was significantly greater than that of P1; $(P3 \times P2)F_2$ was significantly greater than that of P3; and $(P3 \times P4)F_2$ was significantly greater than that of P3.

The MPF's of the F_2 crosses were not significantly different from the backcross generations made in either direction.

The MPF's of the reciprocal crosses in the F_2 were not significantly different.

P3 had a significantly higher MPF than P1. When both P1 and P3 were crossed with P2, the mean pull forces in the F_2 generation were significantly different. The $(P1 \times P2)F_2$ was lower than that of the $(P3 \times P2)F_2$.

Separation at the node was unmeasurable in P2 and P4, but the mean pull force of the $(P3 \times P4)F_2$ was significantly lower than the MPF of $(P3 \times P2)F_2$.

Soft Rot

The criterion used for measuring the tolerance of fruit of two different types of detachment was a comparison of the number of rotting fruit out of each 10 fruit sample at the stated intervals of 3, 5, 7, and 10 days after inoculation. The difference in tolerance between the calyx-detached peppers and peppers with a jagged pedicel within each cultivar is expressed by the data in Table 4.

Table 4. Comparisons of tolerance to soft rot of peppers with and without pedicels and calyces within cultivars.

	Percentage of Rotted Fruit[z]							
	Days after Inoculation							
	3		5		7		10	
Cultivars	With[y]	W/out[x]	With[y]	W/out[x]	With[y]	W/out[x]	With[y]	W/out[x]
Allbig	7	83***	47	97*	50	97	60	100
Avelar	30	77	43	81*	50	93*	63	97*
Early Calwonder	43	50	77	93*	77	100***	77	100***
Hot Portugal	7	57**	17	73***	23	73**	30	73*
Jalapeno	0	0	3	0	3	3	6	3
Keystone Resistant Giant	30	50	66	96	70	96	73	96
Large Red Cherry	13	80**	27	83**	30	83*	50	87*
Yolo Wonder	67	50	87	97	90	100	90	100

*Values significantly different at the 90 percent probability level.

**Values significantly different at the 95 percent probability level.

***Values significantly different at the 99 percent probability level.

[z] Average of three replicates with 10 fruit.

[y] Fruit with pedicel and calyx attached.

[x] Fruit with pedicel and calyx detached.

The fruit of both detachment treatments of 'Yolo Wonder' and 'Keystone Resistant Giant' were very susceptible and no differences in soft rot tolerance were found.

The calyx-detached fruits of 'Allbig' had a significantly higher number of fruits with soft rot at 3 and 5 days after inoculation, but at 7 and 10 days, there were no significant differences between the two detachment treatments.

Three days after inoculation there was no difference in the amount of soft rot between the two detachment treatments in fruits of 'Avelar' and 'Early Calwonder'. However, 5, 7, and 10 days after inoculation the number of calyx-detached fruits which had soft rot was significantly higher for both cultivars.

The jagged-pedicel fruits of 'Hot Portugal' and 'Large Red Cherry' were consistantly more tolerant to soft rot infection than their calyx-detached counterparts.

There was no significant difference in the tolerance to soft rot between the two detachment treatments in 'Jalapeno' fruits; both demonstrated a high tolerance to soft rot.

The percentage of fruit showing rot varied greatly among the cultivars. 'Yolo Wonder' was the least tolerant cultivar having, in 10 days, an average of 90 and 100 percent fruit rot in the jagged-pedicel and calyx-detached treatments. 'Jalapeno', on the other hand, was the most tolerant with six and three percent of its fruit rotting in 10 days.

When the tolerances to soft rot among the cultivars with the jagged pedicels and calyces attached were statistically tested, it was found that fruits of 'Yolo Wonder', 'Early Calwonder', 'Keystone

Resistant Giant', 'Allbig', and 'Avelar' were not significantly different in their tolerances at 5, 7, and 10 days (Table 5). Fruits of 'Large Red Cherry' and 'Hot Portugal' were significantly more tolerant than those of 'Yolo Wonder' in 10 days. 'Large Red Cherry' fruits, on the other hand, were less tolerant, statistically, than fruits of 'Jalapeno' in the same time period. 'Jalapeno' fruits were significantly more tolerant than the fruits of all tested cultivars, with the exception of 'Hot Portugal' at the end of 10 days.

The greatest difference between cultivars was the rapidity in which rot symptoms appeared. All of the 'Early Calwonder' fruits which were to show rot exhibited rot in 5 days, while 67 percent of the 'Yolo Wonder' fruit had developed soft rot by the third day. 'Keystone Resistant Giant', 'Allbig', 'Avelar', and 'Large Red Cherry' were similar in that the greatest percentage of the rot symptoms were observed by 5 to 7 days, but a few fruit were still developing symptoms up to the end of 10 days after inoculation.

The data in Table 6 demonstrates the comparative tolerance among the same cultivars when the calyces and pedicels have been removed from the fruit. Generally, the soft rot symptoms appear much more rapidly than when pedicels and calyces are attached. Five days after inoculation, with the exception of 'Jalapeno' fruits, 73 to 97 percent of fruits of the cultivars show soft rot symptoms. The fruits of 'Jalapeno' are significantly more tolerant than those of all other cultivars tested at 3, 5, 7, and 10 days. 'Hot Portugal' fruits are not significantly more tolerant than those of 'Large Red Cherry' at 10 days, but are more tolerant than the remaining cultivars. 'Large Red Cherry', 'Avelar', 'Keystone Resistant Giant', 'Allbig', 'Early

Table 5. Comparison of tolerance to soft rot of pepper fruit among cultivars with pedicels and calyces attached.[z]

	Percentage rotted fruit[y]			
	Days after inoculation			
Cultivar	3	5	7	10
Yolo Wonder	67a	87a	90a	90a
Early Calwonder	43ab	77ab	77ab	77ab
Keystone Resistant Giant	30bc	66ab	70ab	73ab
Allbig	7c	47abc	50abc	60ab
Avelar	30bc	43abc	50abc	63ab
Large Red Cherry	13bc	27bc	30bcd	50b
Hot Portugal	7c	17c	23cd	30bc
Jalapeno	0c	3c	3d	6c

[z] Average of three replicates with 10 fruit.

[y] Values in columns not having common letter are significantly different at the 95 percent probability level by Duncan's new multiple range test.

Table 6. Comparison of tolerance to soft rot of pepper fruit among cultivars with pedicels and calyces removed.[z]

	Percentage rotted fruit[y]			
	Days after inoculation			
Cultivar	3	5	7	10
Yolo Wonder	50b	97a	100a	100a
Early Calwonder	50b	93a	100a	100a
Keystone Resistant Giant	50b	96a	96a	96a
Allbig	83a	97a	97a	97a
Avelar	77ab	87a	93ab	97a
Large Red Cherry	80ab	83a	83ab	87ab
Hot Portugal	57ab	73a	73b	73b
Jalapeno	0c	0b	3c	3c

[z] Average of three replicates with 10 fruit.

[y] Values in columns not having common letter are significantly different at the 95 percent probability level by Duncan's new multiple range test.

Calwonder', and 'Yolo Wonder' fruits are not significantly different in their tolerance to soft rot 10 days after inoculation.

Customer Preference

All peppers displayed for the customer preference test were of the 'Yolo Wonder' cultivar. They were harvested at the mature green stage, and were of the same general size and shape. Every possible measure was taken to insure that the only difference in the displayed peppers was that the fruit of one contained a calyx and a short broken pedicel, while the other had a white stem scar where the pedicel and calyx had been attached to the fruit.

Table 7 shows the number of each type of pepper sold and that number as a percent of the total peppers sold.

In seven out of the eight weeks, slightly more peppers with a white stem scar, instead of a calyx and pedicel, were sold. There was, however, no statistical difference in the customer preference between the two pepper types in this test.

Storage Quality

No difference in weight loss could be found between peppers with a calyce and a short jagged pedicel, and those having a large exposed stem scar when stored at 21.1°C and 80% R. H.

The mean weight loss of peppers with a stem scar was 11.54 percent, while those with a pedicel and calyx had a mean weight loss of 10.24 percent.

When compared on the basis of percent weight loss plus the calyx weight loss, there is still no significant difference between the two

Table 7. Comparison of customer preference between fruit of the pedicel-calyx detachment type and the jagged pedicel type.

	Peppers with pedicel and calyx		Peppers w/out pedicel and calyx	
Week	Peppers sold	Percent of total sold	Peppers sold	Percent of total sold
1	19	40	29	60
2	31	49	33	51
3	19	38	31	62
4	26	47	29	53
5	35	48	38	52
6	20	43	27	57
7	38	55	32	45
8	18	44	23	56
Total	206	46	242	54

treatments. The mean total weight loss of peppers with a stem scar during storage was 12.96 percent, while those with a pedicel and calyx had a mean total weight loss of 12.26 percent.

No difference could be found between the pepper treatments as to percent ripening in the 14 day time period and to the visual quality of the fruit.

DISCUSSION

Incorporation of a character for the detachment of pepper fruits from the plant at the calyx and at the node would facilitate the development of bell pepper cultivars for both hand and mechanical harvesting.

The lines PI 224405 (P1) and 68-14 (P3) were used in the analysis and crosses because their fruit separated readily from the plant at the node and at the calyx.

Plants of PI 224405 produced an abundance of small, elongate, pungent fruit. The ripe fruit of P1 also demonstrated the soft wall character. Observations of the segregation of the soft wall character in the F_2 crosses of P1 and P2 indicated that it was not a factor in the pull force of mature green fruit.

Plants of 68-14 produced small, oblate pungent fruit that were deep purple in the immature stages. When P3 was selfed, the resulting plants produced fruit ranging from oblate to elongate fruit shape, and purple through lettuce green fruit color. The genetic heterozygosity of P3 for these characters was evident also in the variety of fruit shapes and colors in the progeny of the crosses.

The cultivar, 'Early Calwonder' (P2) produce large, cedar green, bell fruits as does the line 23-1-7 (P4). The fruits of P2 and P4 will not separate readily either at the node or at the calyx. To remove the fruit from the plant, the pedicel must be broken or cut.

Pl was crossed with P2, and P3 was crossed with P2 and P4 to determine if detachment at the calyx and/or detachment at the node could be transferred genetically. Fruit detachment between the calyx and pod would be desirable for harvesting and storage purposes because of the absence of a jagged pedicel to puncture or scar neighboring fruit.

The diameter of the stem scar is significantly correlated with the mean pull force (MPF) at the calyx in the F_2 and backcross progenies of Pl crossed with P2. The mean pull force of Pl is not significantly correlated with its stem scar diameter, however. The MPF at the calyx of P3 is significantly correlated with the stem scar diameter, but the progeny of the (P2 x P3)F_2 are the only plants with P3 as a parent that have fruit that have significant correlation between the SSD and the MPF at the calyx.

The unadjusted mean pull force at the calyx of Pl is 0.68 kg, while that of P2 is unmeasurable in that no detachment occurs. The fruit of the F_2 progeny of the cross (Pl x P2) have a MPF of 3.11 kg. This is significantly higher than that of Pl. The MPF at the calyx of fruit of the backcross progeny of (P2 x Pl) x Pl is significantly lower than those of the F_2 of the cross (P2 x Pl). This points to fruit-calyx detachment being under genetic control.

The mean pull forces of the F_2 reciprocal crosses of Pl and P2 are not significantly different. Also, no significance is found between mean pull forces of F_2 fruits of P3 and P2 reciprocal crosses.

The mean pull forces of fruit from F_2 progeny, when Pl and P3 are used as the female parents and pollen from P2 is used in the initial crosses, are not significantly different. However, if Pl and P3 are used in the initial crosses as pollen parents and crossed with P2, the mean pull force of fruit in the F_2 generation is significantly different. The differences in the mean pull forces of the (P2 x P1)F_2 and the (P2 x P3)F_2 progeny can probably be ascribed to the high heterozygosity of the P3 parent.

The mean pull force of fruits from P3 is significantly lower than the MPF of fruits of the F_2 progeny of the P3 x P2 cross. The MPF of P3 fruits is not, however, significantly different from the MPF of fruits from the F_2 progeny of the cross P3 x P4. The fruits from the (P3 x P4)F_2 progeny also have a significantly lower MPF than those from the (P3 x P2)F_2. This indicates that although no separation can be found at the fruit-calyx detachment site in P2 and P4, there is a difference in the lines either in the direct genetic control of calyx detachment or in factors modifying detachment, which could be morphological in nature.

Progeny of P1 and P3 demonstrated great diversity in phenotypic characters and were far from being homozygous lines. Deviations from expected results in F_2 and backcross progeny in crosses using one of these as parents, could be due to the great heterozygosity of the lines or to sampling error.

The small sampling of F_1 progeny done in the fall of 1972, indicated that the MPF of F_1 and F_2 plants were similar. It is reasonable to assume then, that the calyx detachment character is dominant or at least additive in nature. If the character was recessive, very few F_1 fruits would have demonstrated a measurable detachment.

The fact that the mean pull force of 68-14-1-1 was approximately 1 kg lower than the MPF of 68-14 (P3) proves that selection can be made for lower detachment at the calyx.

The pull force of each fruit was measured by a direct pull on the fruit-pedicel axis. It was noted that many fruit that demonstrated a high pull force on this axis separated very readily when the angle was changed to 45 degrees.

Detachment between the calyx and fruit results in a fruit with a stem scar in which the placental tissue is exposed (3). Several questions arose as to the feasibility of using this character because of the exposed area.

The first question was whether an exposed stem scar would allow moisture to escape from the placenta and fruit walls, effectively lowering the storage quality of the fruit. 'Early Calwonder' fruits were stored at 21°C (70°F) and 80% relative humidity, which is 11 to 14° higher temperature and 5 to 10% lower humidity than recommended for pepper storage. Fruits with jagged pedicels, the type usually found in hand harvested fruit, were stored and compared with fruits demonstrating a stem scar from mechanically removed calyces. The results showed that there were no significant differences in storage quality as measured by weight loss between the jagged-pedicel treatment and the calyx-detached treatment for this cultivar under these storage conditions.

A second question that arose was whether the customer would prefer a fruit with the pedicel attached over one with a stem scar. In an eight week study at one location, it was found that there was no customer preference between the fruit of 'Yolo Wonder' containing a pedicel and 'Yolo Wonder' fruit with a stem scar where the pedicel and calyx had been removed.

The third question, and a very important one, was whether the fruit with the calyces and pedicels detached, exposing the placental tissue in the stem scars, would be more susceptible to bacterial soft rot than hand harvested fruit with a jagged pedicel. In the cultivars tested, there was no difference in tolerance to soft rot between the two treatments in fruit of 'Allbig', 'Keystone Resistant Giant', 'Yolo Wonder', and 'Jalapeno' 10 days after inoculation. Fruits of the first three cultivars were very susceptible to soft rot in both treatments. Fruits of 'Jalapeno' in both treatments were very tolerant to soft rot. Fruits in the calyx-detached treatments of 'Early Calwonder', 'Hot Portugal', and 'Large Red Cherry' were more susceptible to soft rot 10 days after inoculation.

When fruits of cultivars in the same treatment were compared, it was found that there were significant differences among cultivars in their tolerance to soft rot.

This indicates that any statement about the differences in tolerance to soft rot between detachment types should be prefixed by the cultivar name and possibly even the lot number.

The possibility that tolerances to soft rot may be inherited has been suggested in tomatoes (1). This may also be true in peppers, and if so, the tolerances would have to be watched closely if the calyx-detached character is to be incorporated into a bell cultivar.

Detachment of fruit from the plant at the node is an alternative location for fruit separation for mechanical harvesting. The node is a natural (abscission) site of fruit detachment. The harvested fruit would contain the calyx and pedicel, but the pedicel would have a blunt end as opposed to a jagged end that is now found in hand harvested fruit.

The parents, P1 and P3, have a significantly lower mean pull force for node detachment than does the F_2 of the crosses of P1 x P2, and P3 x P2 and P4. The fruits of P2 and P4 will not separate at the node. Fruits of the F_2 and backcross progenies have relatively low mean pull forces which indicates genetic control for the character.

The incidence of soft rot has been reported to be much lower for pepper fruits with a natural (abscission) separation as opposed to those of the jagged-pedicel type (11).

The pull forces for separation per plant were generally lower at the node detachment site than the fruit-calyx site. The node type detachment can also be found in lines offering larger fruits than those demonstrating the calyx detachment.

The pedicels in many large-fruited cultivars are thick and rigid and easily broken. Many pendant types on the other hand, have a flexible pedicel that is rather resistant to being broken. Field observations have indicated that the relative difference between the two pedicel types is the thickness of the cortex. A range of cortex thickness was observed in the F_2 progeny of crosses between the two types. No comparative evaluation of cortex thickness was performed, but it may be an important character if the node detachment site is incorporated into commercial bell cultivars.

SUMMARY

PI 224405 (P1) and 68-14 (P3), two lines whose fruits separate readily at the node and at the calyx in the mature green stage, were crossed with 'Early Calwonder' (P2) and 23-1-7 (P4) for evaluation of detachment characters in F_2 and backcross progenies.

Statistical tests of pull force measurements indicated that fruit detachment force differences at the node and at the calyx were heritable. The pull forces of selections from plants of 68-14 also indicated that the mean pull forces of calyx detachment could be lowered in succeeding generations by selection.

The diameter of the stem scar was significantly correlated with the mean pull force at the calyx in F_2 and backcross progenies of P1 crossed with P2. The fruit width was also correlated with the pull force at the node in several populations.

The pull forces for separation per plant were generally lower at the node detachment site than at the fruit-calyx site.

The fruits of eight cultivars were tested to determine if fruits with a stem scar were more susceptible to soft rot than fruits with a jagged pedicel. In five out of eight cultivars there were no significant differences in tolerance between the treatments, while in fruits of three of the cultivars there were significant differences, with the fruits with stem scars being more susceptible.

When fruits of cultivars in the same treatment were compared, it

was found that there were significant differences among cultivars in their tolerances to soft rot.

In comparisons of fruits with a stem scar as opposed to fruits with a jagged pedicel, it was found that there were no significant differences in the storage quality of the two types at 21.1°C and 80% relative humidity in 14 days.

There were no customer preferences between fruits with a stem scar and ones with a jagged pedicel when the two types of fruits were sold at one location during an eight week period.

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BIOGRAPHICAL SKETCH

William Martin Stall was born April 14, 1944, at Bluffton, Ohio. He grew up and worked on a family farm in Putnam and Hancock Counties in northwestern Ohio. In May, 1962, he was graduated from Pandora-Gilboa High School, Pandora, Ohio. He entered Ohio Northern University, Ada, Ohio, in September of 1962 and transferred to the Ohio State University in September of 1964. He received a Bachelor of Science in Agriculture from Ohio State majoring in Botany and Plant Pathology. During the summers of 1964 through 1967, he worked as a research assistant in the Agricultural Research Department of Libby, McNeil and Libby, Leipsic, Ohio.

He entered the University of Florida, Gainesville, Florida, in September of 1967. During his studies he was graduate research assistant in the Vegetable Crops Department. He received the degree, Master of Science in Agriculture in August, 1969.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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